



# **Fundamental Aeronautics Program: Overview of Project Work in Supersonic Cruise Efficiency**

The Supersonics Project, part of NASA's Fundamental Aeronautics Program, contains a number of technical challenge areas which include sonic boom community response, airport noise, high altitude emissions, cruise efficiency, light weight durable engines/airframes, and integrated multi-discipline system design. This presentation provides an overview of the current (2011) activities in the supersonic cruise efficiency technical challenge, and is focused specifically on propulsion technologies. The intent is to develop and validate high-performance supersonic inlet and nozzle technologies. Additional work is planned for design and analysis tools for highly-integrated low-noise, low-boom applications. If successful, the payoffs include improved technologies and tools for optimized propulsion systems, propulsion technologies for a minimized sonic boom signature, and a balanced approach to meeting efficiency and community noise goals.

In this propulsion area, the work is divided into advanced supersonic inlet concepts, advanced supersonic nozzle concepts, low fidelity computational tool development, high fidelity computational tools, and improved sensors and measurement capability. The current work in each area is summarized.



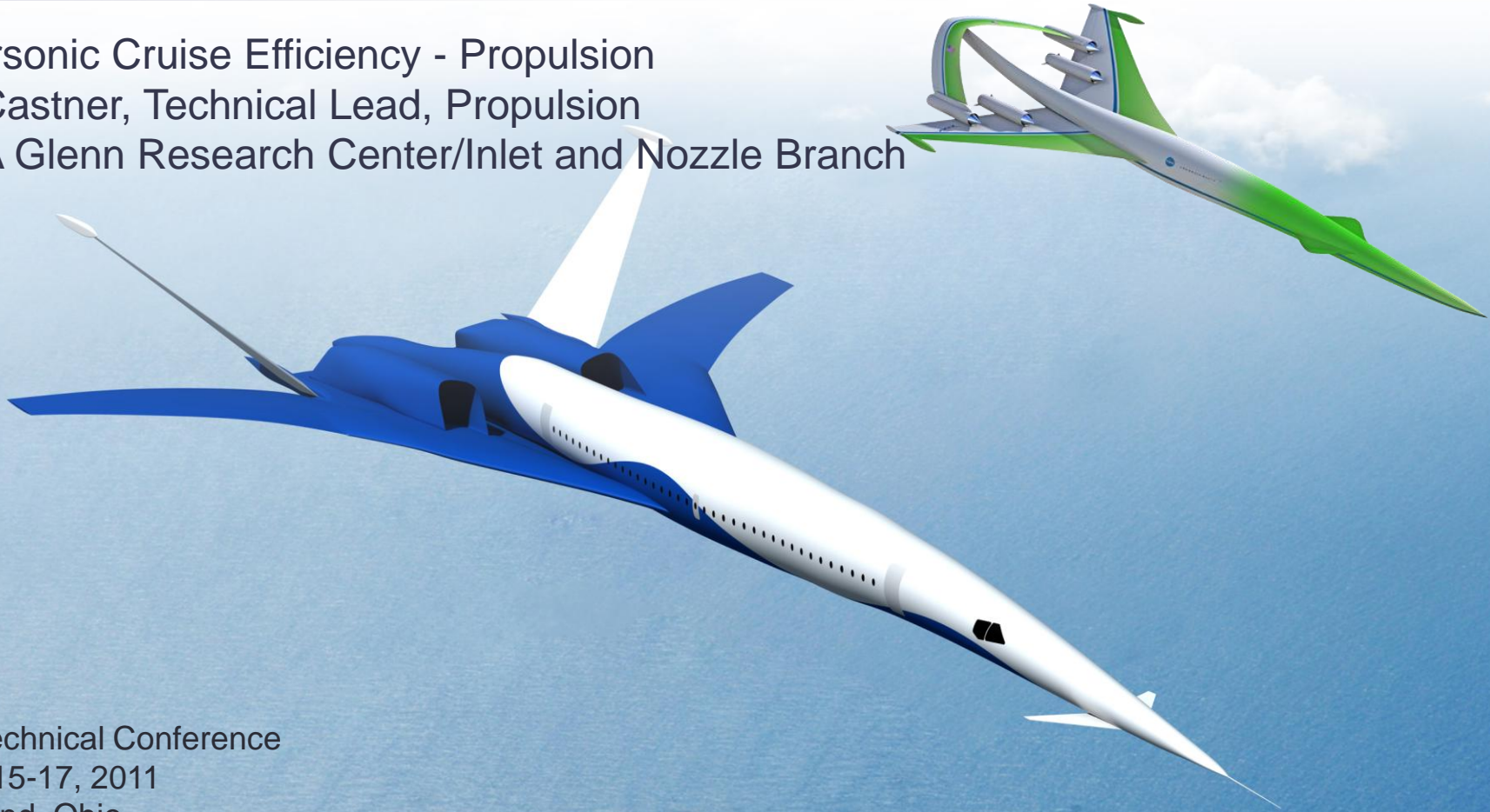
# Fundamental Aeronautics Program

## *Supersonics Project*

Supersonic Cruise Efficiency - Propulsion

Ray Castner, Technical Lead, Propulsion

NASA Glenn Research Center/Inlet and Nozzle Branch



2011 Technical Conference

March 15-17, 2011

Cleveland, Ohio

[www.nasa.gov](http://www.nasa.gov)

# Supersonic Project Technical Challenges



**Sonic Boom Community Response**

**Airport Noise**

**High Altitude Emissions**

**Supersonic Cruise Efficiency**

- Tools and technologies for integrated propulsion, aerodynamic analysis and design



**Light Weight, Durable Engines/Airframes**

**Aeroservoelastic Analysis and Design**

**Integrated Multi-Discipline System Design**

- Integration of Supersonic Aircraft in NextGen System (with Airspace Program)

# Technical Challenge: Supersonic Cruise Efficiency



## What are we trying to do?

- Develop and validate high-performance supersonic inlet and nozzle technologies and design/analysis tools for highly-integrated, low-noise, low-boom applications

## What is our approach?

- Develop high-performance, highly-integrated, low-boom inlet concepts (including inlet-fan interaction effects and consideration for variable cycle engine concepts).
- Develop high-performance, highly-integrated nozzles, include jet plume effects on sonic boom.
- Develop inlet design tools, advanced models for flow control (e.g. vortex generators, bleed).
- Apply high-fidelity CFD approaches (hybrid RANS/LES, LES) to gain more insight into flow physics of shock wave/boundary layer interactions and refine high-performance / wide-operability fan and compressor models.

## What are the payoffs if we are successful?

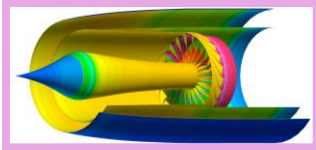
- Improved technologies and tools for optimized propulsion systems.
- Propulsion technologies for a minimized sonic boom signature.
- Balanced propulsion approach to meeting efficiency and community noise goals.

# Technical Challenge: Supersonic Cruise Efficiency - Propulsion



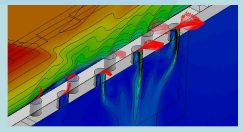
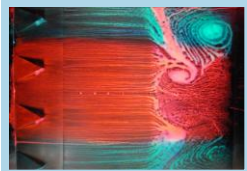
## Technical Challenge Validated

- National R&D plan (Mobility Goal 5, Nat'l Security Goal 2, E & E Goal 3)
- NASA N+2, N+3 Systems Studies
- Input from OGA stakeholders
- Input from Industry
- NRC 2006 Decadal Survey (A2, A9)



### Multi-Discipline Capabilities

- Coupled inlet/fan analysis capability
- Inlet design tools integrated into design process framework



### Foundational Research

- Flow control experiments for shock wave/boundary layer interactions
- Bleed experiments and model improvements
- Isolated jet plume effects for sonic boom
- Fundamental supersonic boundary layer experiments
- RANS, Hybrid RANS/LES, LES CFD studies

### System Design

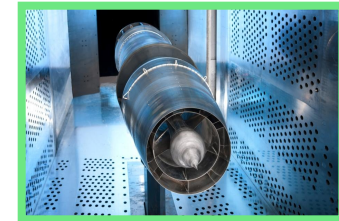
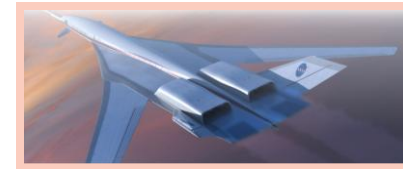
### Multi-Discipline Capabilities

### Discipline Level Capabilities

### Foundational Physics & Modeling

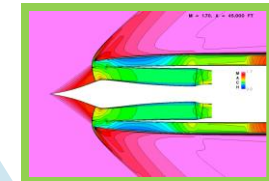
### Benefits of Successful Completion

- Fast, accurate, robust design process for configurations with high performance and low boom.
- Optimized propulsion systems.
- Meet airport noise requirements.



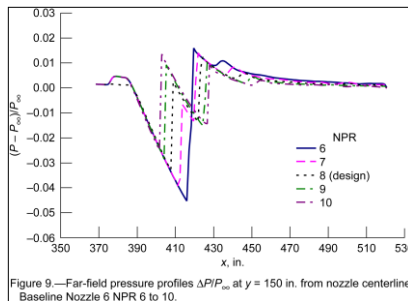
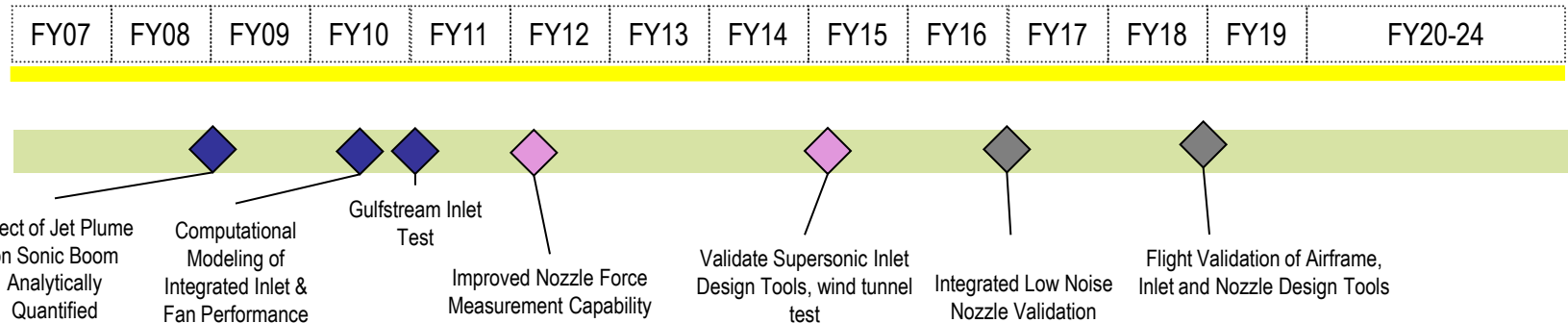
### Discipline Capabilities

- Supersonic inlet design and analysis tools
- Supersonic nozzle analysis and test capability, including sonic boom effect





# Measuring Progress: Supersonic Cruise Efficiency - Propulsion

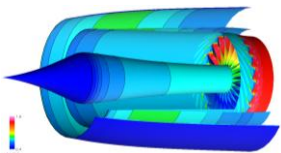


## What are the intermediate and final exams to check for success?

- Validate supersonic inlet design tools on integrated supersonic inlets (FY14)
- Validate integrated low noise nozzle (FY16)
- Flight validation of low boom/low drag design, including propulsion effect completed (FY18)

## Recent Progress Toward Meeting Technical Challenge

- Analytically quantified effect of jet plume on sonic boom (FY08)
- Developed computational models to predict integrated inlet and fan performance and operability and compare models to experimental data (FY10)
- Completed large-scale low-boom relaxed external compression inlet development and test in 8x6-ft tunnel (FY10)
- Developed improved nozzle force measurement capability (FY10)



# Research Elements - Propulsion

---



- Advanced Inlet Concepts
  - Low Boom/High Performance Inlet Development
- Advanced Nozzle Concepts
  - Improved Nozzle Force Measurements
  - Jet Plume Effects on Sonic Boom
  - Low Boom/Low Noise/High Performance Nozzle Development
- Low Fidelity Computational Tools
  - Supersonic Inlet Design Tools
  - BAY Vortex Generator Modeling
  - Inlet Bleed Modeling
- High Fidelity Computational Tools
  - High Performance/Wide Operability Fan and Compressor
  - Inlet-Fan Interaction
  - Micro-Array Flow Control, RANS and hybrid RANS/LES CFD
- Improved Sensors and Measurement Capability

# Research Elements

---



Advanced Inlet Concepts



# Key Research Activity

## Low Sonic Boom Inlet Design and Validation



### Objective:

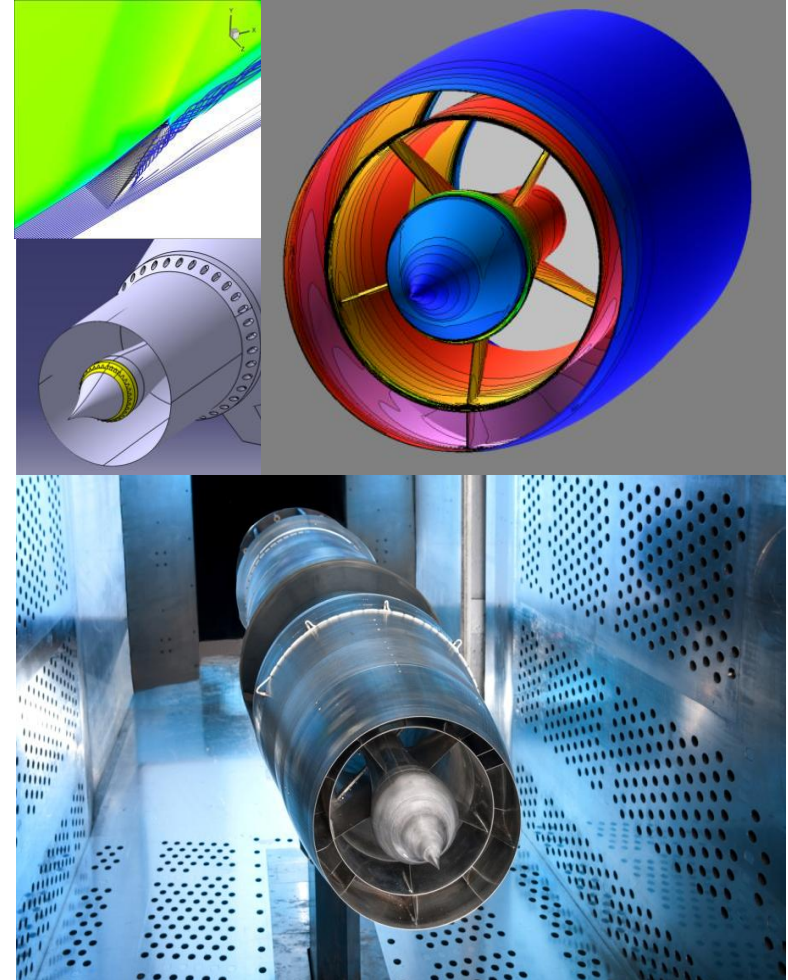
- Explore inlet concepts with potential for high performance and small contribution to sonic boom.
- Develop flow control devices that improve inlet stability and performance with little or no bleed flow.

### Approach:

- Build on successful relationships with AFRL, Gulfstream, and UIUC (NRA).
- Foundational research on micro ramp flow control devices – computational and small scale testing.
- Relaxed isentropic inlet design small scale testing.
- Design of experiments application in RANS CFD.
- Large scale inlet model fabrication and test in GRC 8x6 ft supersonic wind tunnel.

### Significance:

- Demonstrated a low-boom inlet with high recovery, excellent buzz margin, and high operability. Gained confidence in use of modeling and simulation tools to design inlets of this class with flow control.
- Developed a high quality database of results that can be shared with the community.



**Presentations by  
R. Chima and S. Hirt  
Thursday**

# Research Elements

---

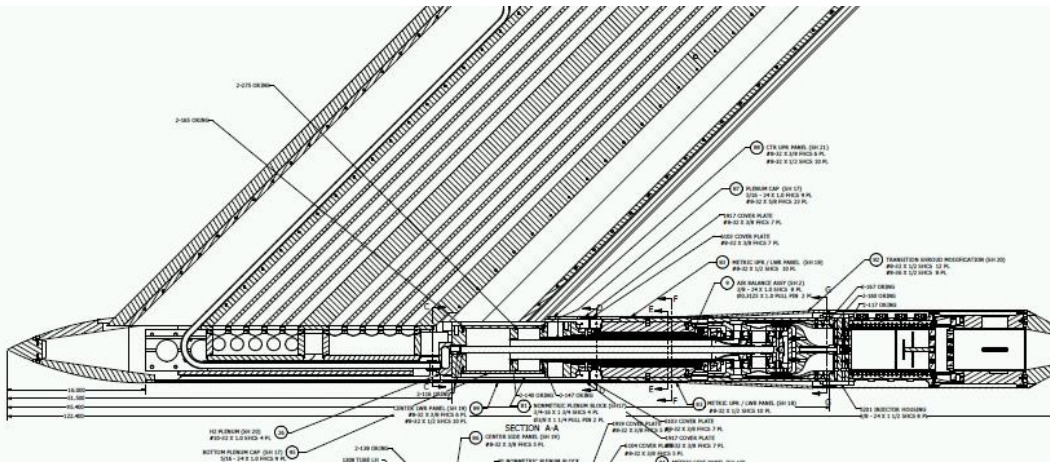
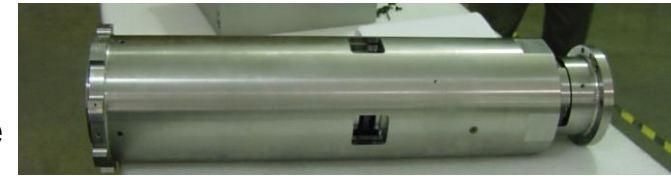


Advanced Nozzle Concepts

# Improved Nozzle Force Measurements

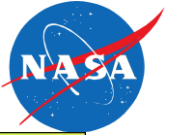


- 6-component flow-through air balance.
  - Triumph Aerospace, Force Measurement Systems.
  - GRC Jet Exit Rig used for advanced nozzle tests in GRC 9'x15', 8'x6' and 10'x10' supersonic wind tunnels.
  - Improved test capability for supersonic nozzles..
  - 10 lb/sec core flow, 3 lb/sec fan flow.
  - Calibration complete in the 6 axis Automatic Balance Calibration System (ABCS), summer 2010.
  - Checkout at NASA Glenn in May 2011.

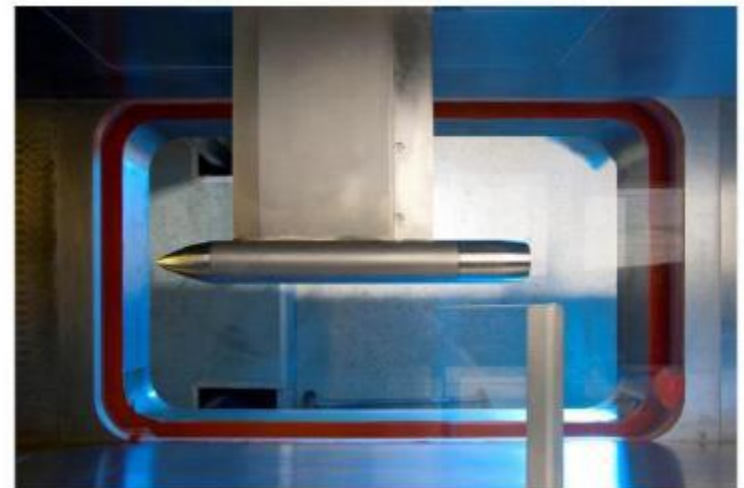
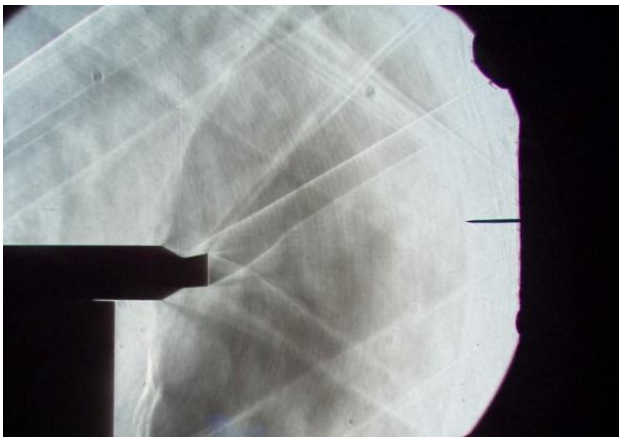
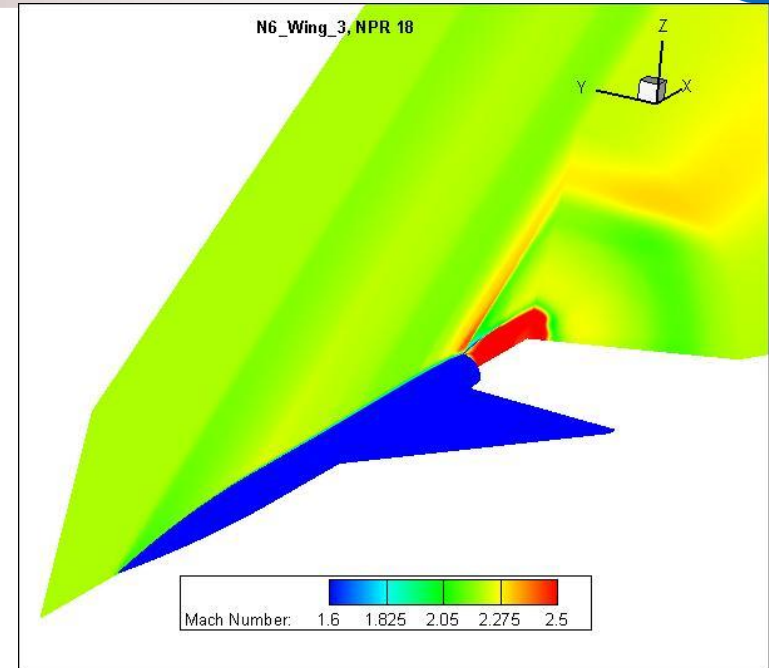


John Wolter and Ray Castner

# Jet Plume Effects on Sonic Boom



- Develop guidelines for nozzle shape, integration and operation for high-performance low-boom operation.
- Small scale wind tunnel testing to compliment NASA Dryden Lift And Nozzle Change Effects on Tail Shock flight test for vectored nozzles.
- Analysis on simplified wing-body-nozzle configurations.
- Analysis:
  - Wind-US, Cart3D & PC-Boom
- Partner with Airport Noise Technical Challenge to develop integrated low noise, low sonic boom nozzle concepts.



Ray Castner

# Research Elements

---



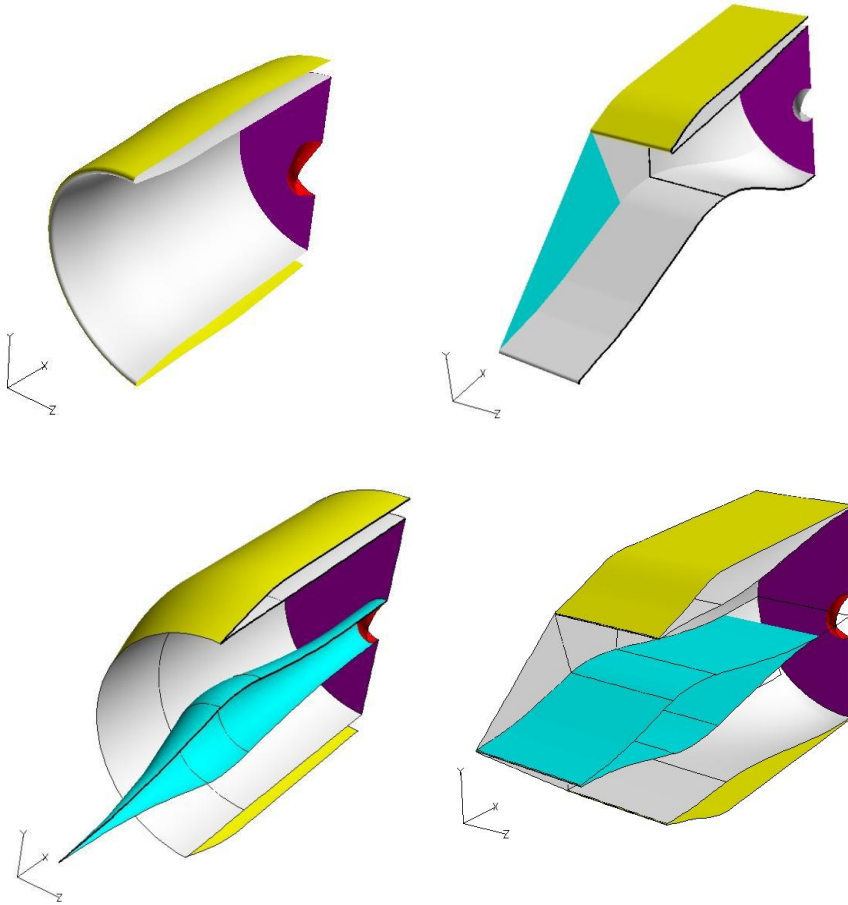
Low Fidelity Computational Tools



# Inlet Design Tools



- SUPIN Code - Modern Design Tool Framework
  - Will link geometry, design and analysis tools together in a modern framework
  - 3D capabilities
  - SUPIN is released as a “Beta” version.
  - An inlet design study planned to design four baseline inlets and estimate their performance for on-design and off-design conditions. CFD analysis will be conducted for comparison of the aerodynamics.

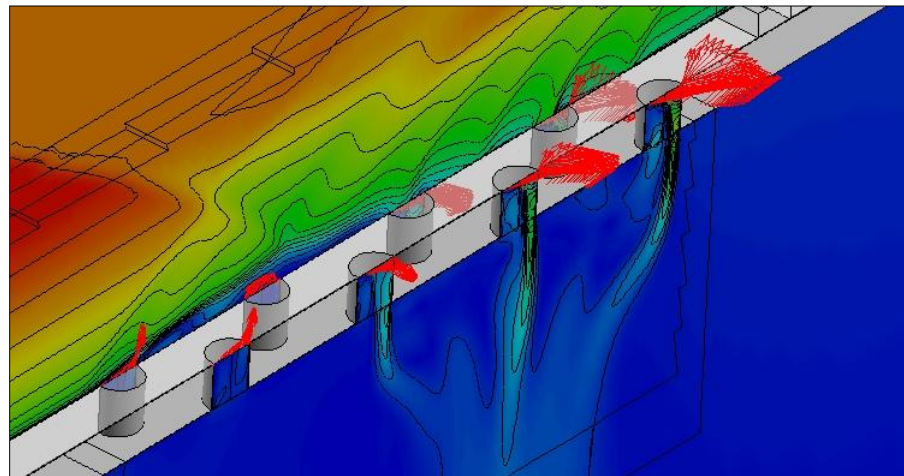


Presentation by Dr. John Slater  
Thursday

# Inlet Bleed Modeling



- Model development and implementation
  - Improvements to current state-of-the-art models
  - Implementation into the Wind-US code
  - Slater, AIAA Paper 2009-710
- Bleed hole simulations
  - NRA: A. Hamed, PI, University. of Cincinnati
  - Detailed information for model development
  - Hamed et al, AIAA Paper 2009-1260
- Fundamental experiments
  - Validate new models
  - Bleed database
  - 15cm x 15cm wind tunnel
  - Testing 2011





# Research Elements

---

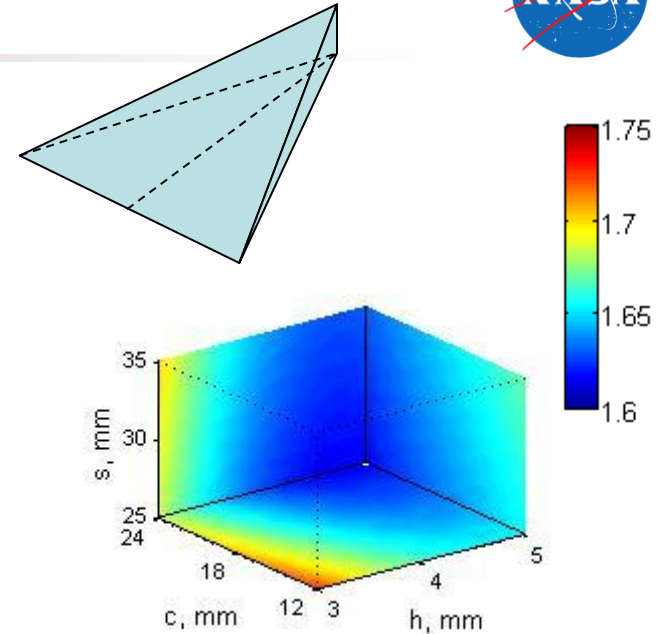


High Fidelity Computational Tools

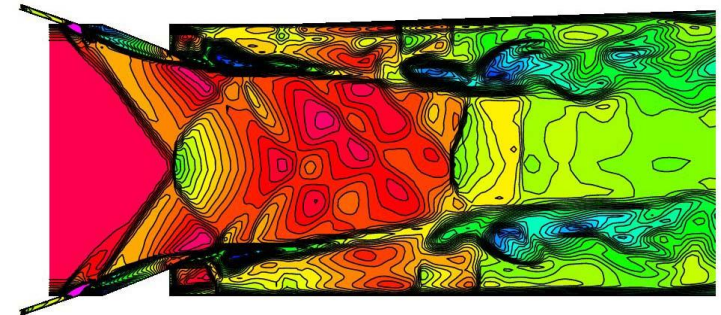
# Inlet Flow Control



- Evolution of Computational Fluid Dynamics
  - Reynolds Averaged Navier-Stokes
    - Initial proof of concept
    - Ramp shaping studies
  - BAY Vortex Generator Model
  - Large-eddy simulation
    - NRA: Eric Loth, PI, University of Illinois
  - Hybrid RANS/LES models of unsteady hybrid blowing/micro ramp flow control
- Evolution of Experiments
  - GRC 15cm x 15cm Oblique shock boundary layer interactions
    - Micro-ramp control
    - Testing completed
  - Normal shock boundary layer interactions
    - Hybrid micro-ramp/micro-blowing control
  - Demonstrated on 8x6 Large Scale Low Boom Inlet Test, 2010
  - 40/60 inlet test planned in 10x10 SWT



*Response Surface of Shape Factor for Control of Oblique Shock Boundary Layer Interaction*

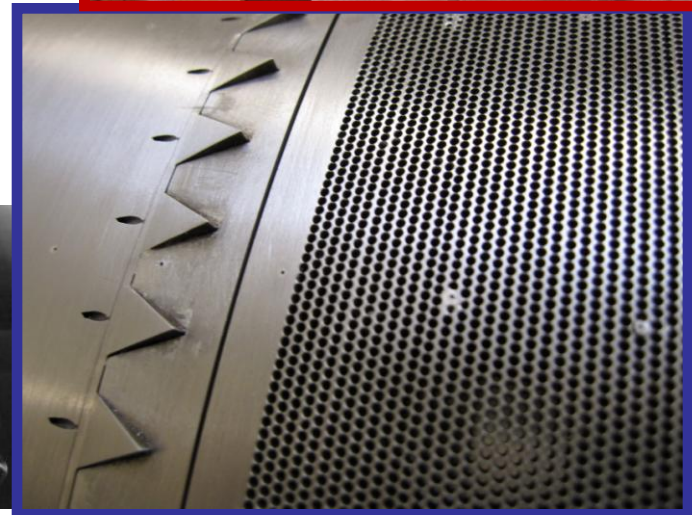
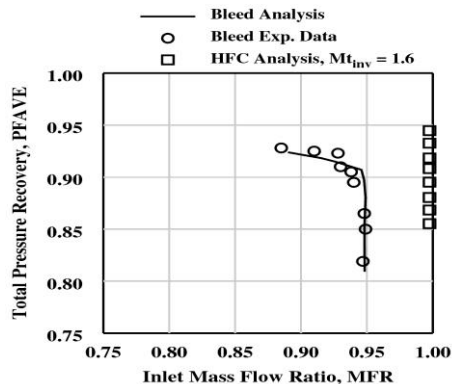


Prototype Hybrid Fluidic Micro-Ramp (HyFM) Actuator, RANS/LES Analysis

# Inlet Flow Control - Large-Scale Testing



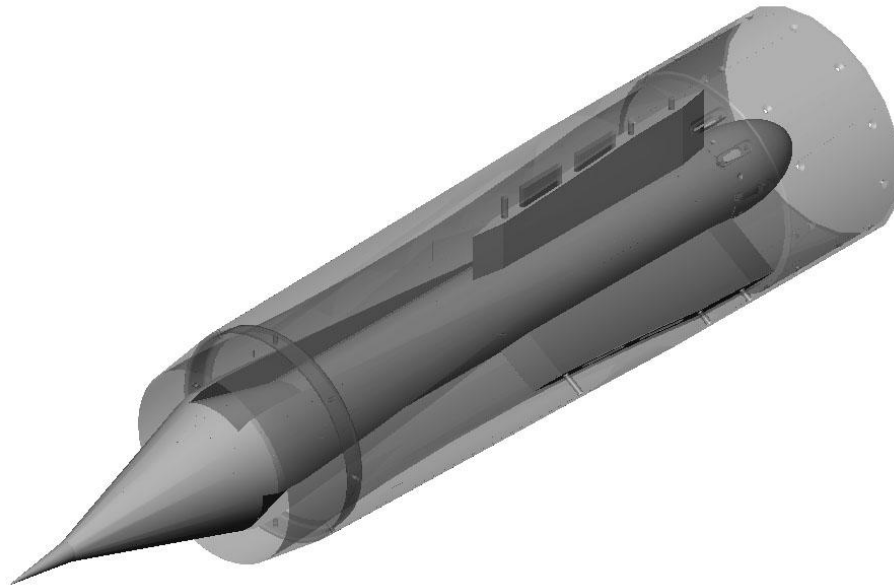
- NASA/Techland 40/60 Inlet
  - NRA: Techland Research Inc.
  - Hybrid micro-ramp/micro-blowing control
    - Control to replace/minimize performance bleed
    - Stability bleed system still necessary
  - Hardware is complete
  - Mach 2.5
  - Mixed-compression inlet
  - 10ft. x 10ft. supersonic tunnel



# Flight Test of the Channeled Centerbody Inlet



- Patented centerbody design allows large throat area variation through simple lightweight system
- Developed by Techland Research under a NASA SBIR
- To be flight tested on the Dryden F-15 in FY11



# Key Milestone Completion (FY10 APG)

## Computational Modeling of Integrated Inlet & Fan Performance



### Objective:

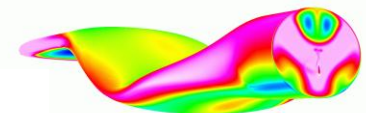
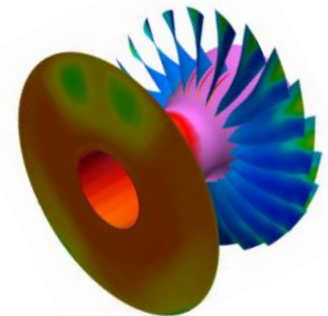
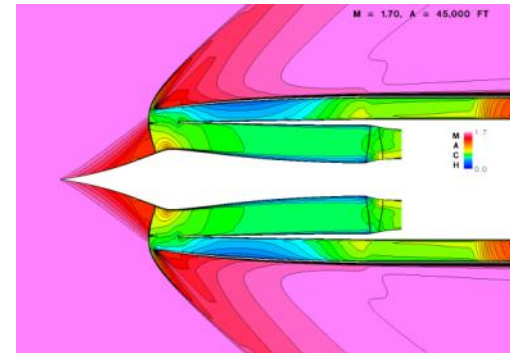
- Understand coupling of inlet and fan flow-fields in unconventional inlet shapes and potential effects on performance and stability.

### Approach

- Two separate tools were developed to assess inlet/fan interactions:
  - Steady-state Reynolds Averaged Navier-Stokes (RANS) analyses yielding fast turnaround for design and development.
  - Unsteady analysis using Unsteady RANS (URANS) or Large-Eddy Simulation (LES).
  - Validation performed with data from the Air Force Versatile Active Integrated Inlet/Fan for Performance Durability (VAIIPR) program and the Gulfstream supersonic inlet and Rolls Royce fan design.

### Significance

- New tools will enable the analysis and design of inlet/fan systems that achieve the levels of efficiency and sonic boom noise required for viable supersonic civil aircraft.
- Allow for the analysis of non traditional inlet shapes for highly integrated design of the next generation of supersonic aircraft



# Research Elements

---



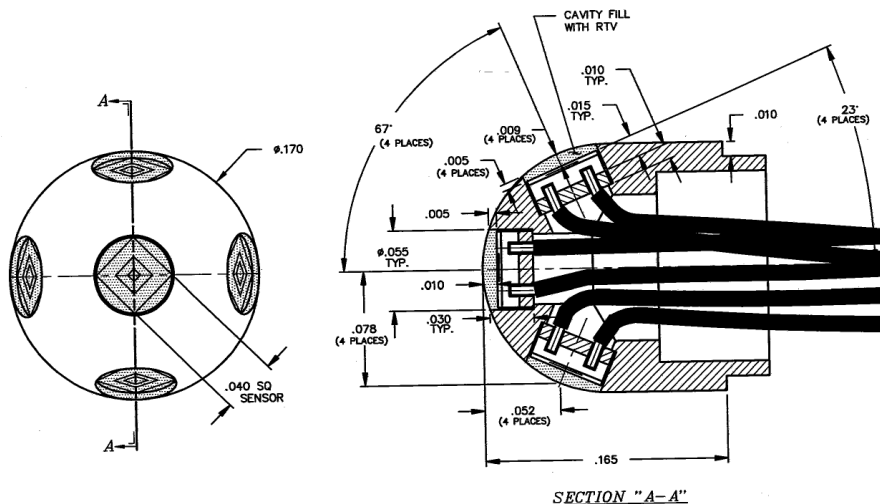
Improved Sensors and Measurement Capability



# Dynamic Flow Angularity Probe



- NRA: Alex Ned, PI, Kulite Semiconductor Products Inc.
- Dynamic inlet distortion measurements.
- 2 versions: 0.170 inch and 0.190 inch diameter head w/ 5 surface mounted Kulite sensors.
- Performance
  - Spatial resolution 0.052 inch minimum.
  - Frequency response up to 4kHz minimum.
  - Flow angle accuracy  $0.5^\circ$  to  $1.0^\circ \pm 35^\circ$  range.
- Prototypes completed.



Alex Ned, R. Castner





# Key Upcoming Events

---

- FAP Meeting Presentations:
  - Large-Scale Low-Boom Inlet Test Overview. Stefanie Hirt, NASA GRC.
  - Computational Analysis of the Large-Scale Low-Boom Supersonic Inlet. Rodrick Chima, NASA GRC.
  - External-Compression Supersonic Inlet Design Code. John Slater, NASA GRC.
- Low-Boom Inlet Development Session - Wednesday, 29 June 2011
  - 29th AIAA Applied Aerodynamics Conference, Honolulu, Hawaii.
- Improved nozzle force measurements
  - 8' x 6' and 10' x 10' Supersonic Wind Tunnels.
    - 6-component force balance for Jet Exit Rig.
    - Checkout testing 2011.
- Large-scale demonstration of micro-array flow control
  - 40-60 inlet .
  - Hybrid micro-ramp/micro-blowing control.
  - 10-foot by 10-foot SWT test in 2012.
- Future Plans
  - Validate supersonic inlet design tools on integrated supersonic inlets (FY14)
  - Validate integrated low noise nozzle (FY16)
  - Flight validation of low boom/low drag design, including propulsion effect completed (FY18)

